AD-A044 699 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 20/3
TRANSITION PROCESSES DURING COMPRESSION OF CYLINDRICAL SHELLS I--ETC(U)
JAN 77 V T MIKHKELSOO, A B NOVGORODTSEV

UNCLASSIFIED FTD-ID(RS)I-1874-76 NL

| OF |
AD
A044 699

END
DATE
FILMED
10-77
DDC

FTD-ID(RS)I-1874-76

AD-A044699

0

FOREIGN TECHNOLOGY DIVISION

TRANSITION PROCESSES DURING COMPRESSION OF CYLINDRICAL SHELLS IN A STRONG MAGNETIC FIELD

By

V. T. Mikhkel'soo, A. B. Novgorodtsev

FTD ID(RS)I-1874-76

EDITED TRANSLATION

FTD-ID(RS)I-1874-76 3 January 1977

FTD-77-C-000025

TRANSITION PROCESSES DURING COMPRESSION OF CYLINDRICAL SHELLS IN A STRONG MAGNETIC FIELD

By: V. T. Mikhkel'soo, A. B. Novgorodtsev

English pages: 15

Source: Izvestiya Vysshikh Uchebnykh Zavedeniy Energetika, NR 10, 1970, PP. 19-24.

Country of origin: USSR
Translated by: Charles T. Ostertag, Jr.
Requester: FTD/ETDP
Approved for public release; distribution unlimited.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	∝	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Υ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ κ	×	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

TRANSITION PROCESSES DURING COMPRESSION OF CYLINDRICAL SHELLS IN A STRONG MAGNETIC FIELD

Engineer V. T. Mikhkel'soo and Engineer A. B. Novgorodtsev

Leningrad Order of Lenin Polytechnical Institute imeni M. I. Kalinina

The compression of thin-walled metallic cylinders in a strong pulsed magnetic field is of interest in respect to the study of the behavior of metals under conditions of rapid deformations, observed during the magnetic-pulsed working of metals [1], with the obtaining of a strong magnetic field by means of flux compression [2]. There is independent significance in the question of the conversion of the energy of a magnetic field into the kinetic energy of an accelerated cylinder [3, 4].

At the TVN [expansion not verified] department of the LPI imeni M. I. Kalinina an experimental investigation was made of the deformation of metallic cylinders in a strong magnetic field, created during the discharge of a capacitor bank with a capacitance $C=12.8$ μF with a stored energy $W_0=92$ kJ (with a charge voltage $U_0=120$ kV) through a matching transformer on a single-turn solenoid (Figure 1). In the tests the change in the radius of cylinders which were arranged coaxally inside of a solenoid was recorded, and oscillograms were made of the magnetic induction inside and outside of the cylinder.

Calculations of the movement of a deformed cylinder without taking into account such factors as the penetration of the field inside of the cylinder, its heating up by vortex currents, and redistribution of current over the surface of the solenoid during deformation give results which differ signficantly from experimental data [3]. The purpose of the present work is a more stringent description of the process of compression, taking into account the listed features of the deformation of a cylinder in the field of a single-turn solenoid.

In the derivation of equations the magnetic field in the working

gap between the solenoid and cylinder B_e is considered uniform. This is valid in the beginning of the process of acceleration of the cylinder, while the working gap is small. With deep compression the field differs from uniform, but on this stage the influence of the external field on the movement of the cylinder is not great. The field inside of the shell is also accepted as uniform. This field has a noticeable influence on movement only on the final sector of compression, when the supposition of its uniformity is fulfilled. Under these conditions the equation of purely inertial movement of the cylinder we write in the form

(1) $$m\frac{d^2R}{dt^2}=\frac{1}{2\mu_0}(B_e^2-B_i^2)2\pi Rl,$$

where R - current radius of the deformed part of the cylinder;

l - its axial length;

m - its mass.

The assumptions made also lead to the following formulas for the inductance of the working gap:

(2) $$L_2=\frac{\mu_0\pi}{l}(R_c^2-R^2),$$

where R_c - radius of the solenoid, and the inductance of the deformed part of the cylinder

$$L_3 = \frac{\mu_0 \pi}{l} R^2. \tag{3}$$

Since the process of compression lasts all told only several tens of microseconds, then it is possible to disregard the heat exchange between the cylinder and the surrounding medium and to write for its heat content q_3 the equation

$$\frac{dq_3}{dt} = i_3^2 r_{30}\left(1 + \frac{\alpha q_3}{c}\right)\left(\frac{R}{R_0}\right)^2, \tag{4}$$

in which the change in the active resistance of the cylinder r_3 is taken into account in the case of compression due to heating and a change in the thickness of the wall during deformation.

In equation (4) i_3 - vortex current in the cylinder; r_{30} and R_0 - initial values of active resistance and the radius of the cylinder; α - temperature coefficient of resistance; c - heat capacity of the cylinder.

A special feature of the single-turn solenoid is the fact that part of its current flows over the end surfaces and does not take

part in the creation of the working field, which is determined by the current which is flowing over the cylindrical surface of the solenoid. In the process of deformation the relationship between the indicated parts of the overall current of the solenoid is changed. This circumstance is taken into account by the approximation formula of equivalent inductance of the solenoid-cylinder system [5]

(5) $$L = \frac{2\pi\mu_0 R_c h}{l + \frac{4h}{\pi}\left(1,46 + \ln\frac{\pi R_c}{4h}\right)},$$

where $h = R_c - R$ - the gap between the solenoid and the cylinder. In the derivation of (5) it is considered that $h \ll R_c$, and the system operates under conditions of a sharp surface effect.

Formula (5) can be presented in the form

$$L = \frac{L_2 L_\tau}{L_2 + L_\tau},$$

where

$$L_2 = \mu_0 2\pi R_c \frac{h}{l}$$

- inductance of the gap,

(6) $$L_\tau = \frac{\mu_0 \pi^2 R_0^2}{2l} \cdot \frac{\frac{R_c}{R_0}}{\left[1,46 + \ln\frac{\pi R_c}{4(R_c - R)}\right]\frac{R_0}{l}} -$$

inductance of the ends of the solenoid.

In the calculations the gap inductance was calculated by formula (2), and the inductance of the ends - by formula (6).

An investigation of the solenoid-cylinder field on a model showed that the ratio of working current of the solenoid to the total current $\frac{i_2}{i_2+i_T}$, calculated with the help of formulas (2) and (6), in the case of the substitution of values $\frac{R_c}{R_0}=1.05$ and $\frac{R_c}{l}=0.5$, corresponding to the real geometric dimensions of the solenoid, differed somewhat from experimental data. This difference is explained by the approximate nature of the formulas themselves and by the very complex distribution of the field in the solenoid-cylinder system. For approximation of the experimental dependence $\frac{i_2}{i_2+i_T}$ in the entire range of change of radius the factor $\frac{R_0+R}{2R_c}$ is introduced into the formula.

The layout for substitution of the installation is shown in Figure 2. The inductance of scattering of the primary circuit L_1, the inductance of magnetization of the transformer L_μ, the resistances of the primary circuit r_1 and the solenoid r_2 are considered constant, and their values are determined according to the oscillograms of discharge current of the bank or the solenoid.

The tested cylinders had an initial diameter of 95 mm and a length of 200 mm. Their other characteristics are given in Table 1.

The system of equations (1)-(4) was integrated on a computer together with the equations for the electrical circuit in Figure 2. The results of the calculation for a sample of type 1 with U_0=120 kV are compared with experimental data in Figure 3. The satisfactory agreement of curves B_e and the radius of the cylinder R/R_0 confirms the correctness of the selection of the parameters of the arrangement and the assumptions made under the given conditions. In the case of low initial voltages for heavy samples the experimental curves R/R_0 lag behind the calculated, which is explained by the influence of the forces of resistance to deformation under these conditions. The curves of the internal field B_i differ strongly only in the case of deep compression, when the accepted description of the change in the parameters of the shell becomes insufficient. In the final stage the field B_i increases rapidly and the cylinder is slowed down.

Based on the maximum value of velocity the efficiency of acceleration $\eta=\frac{mv^2_{\text{макс}}}{CU_0^2}$ was determined. The calculated dependences of on the dimensionless parameter $\beta=\frac{\pi\mu_0 C^2 U_0^2}{ml}$ for different samples are constructed in Figure 4. In the area $\beta>0.2$ the calculated values agree satisfactorily with experimental, with smaller β an increase yields an excessive result.

In Table 2 the calculated values are given for the relative magnitudes of kinetic energy W_K, electromagnetic energy $W_{эм}$, thermal losses in resistances of the installation q_1+q_2 and losses in the sample q_3 by the moment of achievement of the maximum velocity for a sample of type 1.

With a lessening of β there is an increase in the duration of compression and the share of thermal losses increases both in the cylinder and in the remaining resistors of the circuit. With $\beta<0.2$ more than half of all the energy converts into heat. In this case the share of heat losses in the sample is not great - for aluminum it does not exceed 10 , for copper - 5 . Therefore the losses in the cylinder cannot have a significant influence on the conversion of energy during compression.

With an increase of β the share of thermal losses drops and the kinetic W_K and electromagnetic energy $W_{эм}$ are increased. At high values of β the latter reaches almost half of the initial stored energy W_0. During compression on this particular installation the inductance of the loop only doubles, and even in the absence of losses and an optimal value of β 1 the efficiency does not exceed 0.5 [3], i.e., the greater part of the energy is preserved in the form of

electromagnetic. For an increase of efficiency it is necessary to lower the initial inductance of the installation being considered.

For an evaluation of the influence of the individual factors on the efficiency of acceleration the processes in the loop were calculated without consideration of any other factors. For a sample of type 1 the following modes were considered: a) $\alpha=0$; b) $r_2=0$; c) $r_3=0$; d) $r_3=0$, $-- = \infty$; e) $r_3=0$, $-- = \infty$; f) $L_1 = L_2 = \infty$, $r_1=r_2=r_3=0$. In modes a and b the efficiency differs insignificantly from the previously obtained values, i.e., the losses in the solenoid and change in the resistance of the shell due to its heating up have little influence on the efficiency of acceleration.

The calculated dependences of $\eta(\beta)$ for modes c-f are depicted in Figure 4 by the broken lines. It is evident that both the penetration of the field and the presence of a pulsed transformer had an equal influence on the efficiency, although these two factors are more significant than the previous ones. A more noticeable influence is exerted by the flow of part of the solenoid current over its end surfaces, nonconsideration of this factor leads to almost a double overstating of efficiency (curve e). Therefore for an increase of effectiveness of acceleration the design of the solenoid has to be changed in such a way as to reduce the share of current which is flowing over the end surfaces.

Calculation in an idealized layout with disregard of losses and inductances L_{T} and L_{μ} (curve f) gives results which differ still more from actual.

CONCLUSIONS

1. A calculated arrangement has been worked out for compression of thin-walled metallic shells in the field of a single-turn solenoid, taking into account penetration of the field into the shell, its heating up by vortex currents, redistribution of current over the surface of the solenoid, and the presence of a matching transformer in the discharge loop.

2. The accepted inertial model of deformation is applicable with $\beta>0.2$. At smaller values the influence of the forces of resistance to deformation are significant.

3. The most important factors which determine the efficiency of acceleration in the arrangement which is considered are the active resistance and inductance of the primary circuit, and also the fact that part of the current of the solenoid flows on the ends of the

solenoid and do not participate in the creation of the working field.

Submitted by the TOE [expansion not verified] department

[17 Nov 1969]

BIBLIOGRAPHY

1. Birdsall D. H., Ford F. C., Furth H. P., Riley R. E. Magnetic forming. «American machinist», № 6, 1961.

2. Cnare E. C. Magnetic flux compression by magnetically imploded metallic foils. «Journal of applied physics», № 10, 1966.

3. Алиханов С. Г., Будкер Г. И., Кичигин Г. Н., Комин А. В. Схлопывание металлической оболочки под действием магнитного поля. «Прикладная *механика и техническая физика*», 1966, № 4.

4. Linhart J. G. A simplified analysis of the dynamics of plasma guns. «Nuclear fusion», № 1, 1961.

5. Шнеерсон Г. А. Магнитное поле одновиткового соленоида, расположенного соосно с цилиндром или вблизи плоскости. «Изв. АН СССР», Энергетика и транспорт», 1969, № 2.

Figure 1. Solenoid with a deformable sample.

Key: (1) Solenoid; (2) Insulation; (3) Sample.

Table 1. Characteristics of test samples.

Key: (1) Type; (2) Material; (3) Thickness of wall, d_0, mm; (4) Mass, m', kg/m; (5) Active resistance, r_{30}, mohms; (6) Aluminum; (7) Copper.

Figure 2. Arrangement for substitution of discharge loop.

Figure 3. Compression of sample of type 1 with U_0=120 kV. Change in radius of shell: Δ, ▲ - experiment, 1 - calculated. Curves of magnetic induction: 2 - induction outside of the shell; 3 - induction inside of shell; a - experiment, b - calculated.

Key: (1) ms.

Table 2. Distribution of energy during compression of a cylinder.

Key: (1) kV; (2) kinetic; (3) electromagnetic.

Figure 4. Experimental and calculated values of efficiency of acceleration of a shell. Designation of experimental points: x - sample of type 1, O - sample of type 2, ● - sample of type 3, Δ - sample of type 4. Calculated dependences are depicted by curves.

Key: (1) type 1; (2) type 2.

end-1874

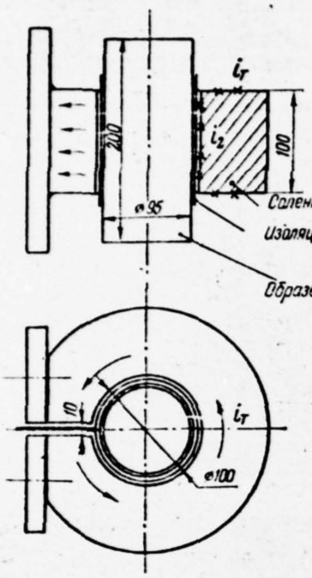

Fig. 1

Table 1

Тип	Материал	Толщина стенки d_0, мм	Масса m', кг/м	Активное сопротивление r_{30}, мом
1	Алюминий	0,5	0,372	0,170
2	Медь	0,2	0,486	0,252
3	Медь	0,4	0,960	0,168
4	Медь	0,6	1,440	0,084

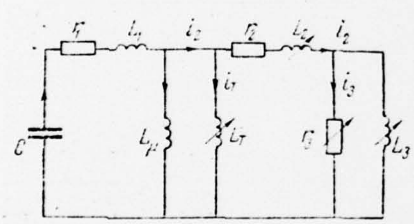

Fig. 2

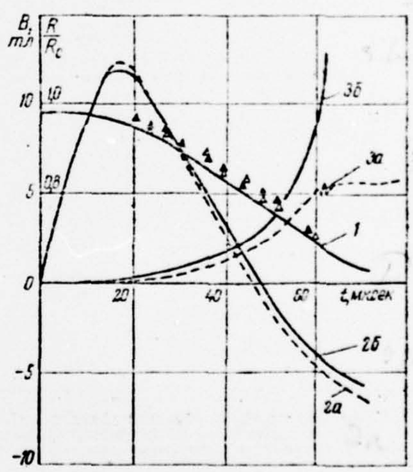

Fig. 3

Table 2

U_0, кв	β	$\frac{W_к}{W_0}$	$\frac{W_{эм}}{W_0}$	$\frac{q_1+q_2}{W_0}$	$\frac{q_3}{W_0}$
40	0,055	0,083	0,118	0,73	0,069
60	0,124	0,108	0,247	0,59	0,055
80	0,220	0,127	0,306	0,53	0,047
100	0,344	0,133	0,428	0,40	0,039
120	0,495	0,155	0,461	0,35	0,034

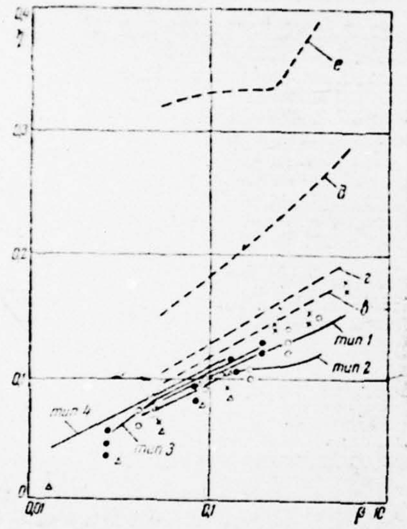

Fig. 4

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: FTD-ID(RS)I-1874-76	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (*and Subtitle*): TRANSITION PROCESSES DURING COMPRESSION OF CYLINDRICAL SHELLS IN A STRONG MAGNETIC FIELD	5. TYPE OF REPORT & PERIOD COVERED: Translation
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): V. T. Mikhkel'soo, A. B. Novgorodtsev	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Foreign Technology Division, Air Force Systems Command, U. S. Air Force	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: 1970
	13. NUMBER OF PAGES: 15
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)	15. SECURITY CLASS. (*of this report*): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

10;20

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)